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Influence of naphthalene acetic acid on fruit setting, fruit quality and yield of *Manilkara achras* L. cv. *Kalipatti* under subtropical conditions

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Manilkara achras L., commonly called sapota, is one of the major fruit crops commercially grown in India. Though India leads in world sapota production, the major problems in sapota are low fruit setting and yield. Hence, we studied these aspects in the commercially grown sapota cv. *Kalipatti* in Punjab conditions. The experiment was conducted to standardize the doses of naphthalene acetic acid (NAA) for fruit setting, quality and yield of sapota at Punjab Agricultural University, Ludhiana during 2016 and 2017. The results revealed that foliar application of 100 ppm NAA at flowering and pea stage during May flowering resulted in higher fruit setting (4.9%) and higher fruit retention (83.5%) over other treatments including control. Similarly, higher fruit setting (18.5%) and higher fruit retention (88.5%) and higher yield (75.90 kg/tree) were recorded in July-August flowering with foliar application of 100 ppm NAA. Fruit quality in terms of average fruit weight (104 g), TSS (22.50 ^{o}Brix) and acidity (0.20%) was also higher in 100 ppm NAA foliar application. Significantly lower PLW (7.56%) was also recorded in 100 ppm NAA treatment. Furthermore, it was observed that profuse flowering occurred during May, July and August months but the later flowering resulted in better crop. The study concluded that fruit setting, quality and yield in sapota cv. *Kalipatti* can be enhanced through foliar application of 100 ppm NAA at flowering and pea stage during July-August flowering under subtropical conditions.

Keywords: Flowering, Plant growth regulators, Sapota

Sapota is native of tropical America especially the South Mexico or Central America. In India, its commercial cultivation is restricted to the coastal regions in the states of Gujarat, Maharashtra, Karnataka, Tamil Nadu and Kerala[1]. India is the largest producer of sapota in the world which occupies an area of 90 thousand hectares with an annual production of 10.89 lakhs metric tonnes[1]. In Punjab, sapota is being successfully grown in the sub-mountainous zone including the area of Pathankot, Hoshiarpur, Roopnagar, Mohali and Patiala districts[2].

Sapota fruit is a good source of digestible sugar and has appreciable amounts of protein, fat, fibre and minerals like calcium, phosphorus and iron. The sapota is a hardy, perennial and evergreen tree and can be grown on a wide range of soils. Sapota tree has unusual flowering and fruiting behaviour. It flowers in abundance but fruit carried out to maturity are very less[3]. It needs warm and humid climate where it flowers and fruits throughout the year. However, in sub-mountain region of Punjab, it gives only one heavy crop during May-June.

Under subtropical conditions, the major problems in sapota are of fruit setting and lower yield. Sapota produces heavy flowering in May-June and July-August flushes. But flowers desiccate due to higher temperature during May-June and very poor fruit setting takes place during June. However, later flowering resulted in better fruit setting and crop is harvested in May-June. Controlling flower bud drop is an important consideration for successful crop of sapota. Application of chemicals before or after flowering is one of the general practices to control erratic flowering and excessive vegetative growth[4]. Application of plant growth regulators (PGRs) at particular stage of flowering and fruit growth and development is one way to tackle the problem of erratic flowering habit and low fruit set[4].

Sapota produces profuse flowering in April-May and July-August under subtropical conditions and the major crop is harvested during May-June. However, the flowers and fruits tend to drop in different stages of development from fruit setting to maturity which drastically reduces the yield. One of the most important causes of fruit drop in fruit crops is decline in the level of endogenous auxin[5]. Foliar application of naphthalene acetic acid (NAA) on fruit bearing sapota tree has been reported to increase fruit set and physicochemical attributes of fruits[5]. Moreover, foliar application of NAA during flowering stage enhances cell elongation and the plasticity of cell wall, and hence improves the qualitative and qualitative parameters of sapota fruits[6]. However, the effect of NAA on fruit setting is dependent on the

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concentration and time of its application. Foliar application of NAA at different floral developmental phases limits the fruit drop resulting in higher fruit retention at various stages[6]. Therefore, its concentration and time of application need to be tested under different agro-climatic conditions for getting desirable results.

The problem of poor fruit set and yield in commercially grown sapota cv. *Kallipati* under subtropics deserves attention. However, only limited information is available regarding the effect of NAA on fruit set, fruit quality and yield of sapota under Punjab conditions. Therefore in the present study, we assessed the effect of foliar application of NAA in sapota cv. *Kalipatti*.

Materials and Methods

The present investigation was conducted at Punjab Agricultural University, Ludhiana during the year 2016 and 2017. Commercial grown sapota cv. *Kalipatti* grafted on *Khirni* rootstock was selected for the research work. All cultural practices were followed as per the Punjab Agricultural University recommendations. The experiment was laid out in Randomized Block Design[7] with three replications and seven treatments. Five to six months old unfruitful shoots were randomly selected in all four directions of the tree and labelled for recording the data on various floral parameters. Different doses of NAA were sprayed one month before flowering and at pea stage during both the flowering seasons. The treatments comprised of T_1-50 ppm NAA,T_2 -75 ppm NAA, T_3-100 ppm NAA, T_4-125 ppm NAA, T_5-0 ppm NAA (water spray) and T_6-control (no spray-farmer practice).The observations on flowering and fruit parameters were recorded for both flowering seasons. Fruit set (%), fruit retention (%) and fruit drop (%) were computed as per methodology given below.

$$Fruit\ Set\ (\%) = \frac{Number\ of\ Fruit\ lets}{Number\ of\ flowers} x\ 100$$

$$Fruit\ Retention\ (\%) = \frac{Total\ number\ of\ fruit\ harvested}{Total\ number\ of\ fruit\ set} x\ 100$$

$$Fruit\ drop\ (\%) = \frac{Total\ number\ of\ fruit\ set - Total\ number\ of\ fruits\ harvested}{Total\ number\ of\ fruit\ set} x\ 100$$

After harvesting mature fruits during May, the fruit yield per tree was recorded in each treatment. For recoding quality parameters, fruits were then wrapped in newspaper and ripened at room temperature (32°C) in corrugated fibre boxes. TSS content was determined with Erma hand-held refractometer, Japan and fruit acidity was estimated as per standard method[8]. Critical difference at 5% level of significance was computed to compare the statistical different of treatment means. Analysis of variance was conducted for various quantitative traits using 9.3 version of SAS (Statistical analysis system) software.

Results and Discussion

Effect of NAA on flower drop and fruit set

The data pertaining to the effect of NAA on flower drop and fruit set are given in Table 1. The results revealed that foliar application of 100 ppm NAA before flowering and at pea stage in May flowering was found significantly superior over other treatments including control in reducing the flower drop and increasing fruit set. Foliar spray of 100 ppm NAA at both the stages reduced the flower drop (95.1%) and increased fruit set to 4.9%. With the increased NAA concentration (150 ppm), the flower drop increased to 99.4% and fruit set was decreased to 0.6%. The control treatment (farmer's practice) where no spray was done, recorded the second highest flower drop (98.9%) and the lowest fruit set (1.1%). Furthermore,

Table 1 — Effect of NAA on flowering (May and August), fruit setting and retention in sapota cv. *Kalipatti* at Ludhiana during 2016 and 2017 (mean data of two years)

Treatment	No. of flower buds per shoot		Flower drop (%)		Fruit set (%)		No. of fruits per shoot		Fruit drop (%)		Fruit retention (%)	
	May	August	May	August	May	August	May	August	May	August	May	August
50 ppm NAA	69.8^{c}	42.3^{abc}	97.7^{bc}	90.2^{abc}	2.3^{cde}	9.8^{bcde}	1.6^{bcde}	4.2^{bcd}	22.3^{bcde}	16.3^{cdef}	77.7^{bc}	83.7^{ab}
75 ppm NAA	54.6^{cdef}	28.0^{def}	96.5^{cdef}	86.4^{abcdef}	3.5^{ab}	13.6^{bc}	1.9^{bcd}	3.8^{cde}	21.5^{bcdef}	18.2^{bcde}	78.5^{b}	81.8^{bc}
100 ppm NAA	94.3^{a}	32.0^{d}	95.1^{efg}	81.5^{g}	4.9^{a}	18.5^{a}	4.6^{a}	5.9^{ab}	16.5^{g}	11.3^{g}	83.5^{a}	88.7^{a}
125 ppm NAA	86.0^{ab}	43.8^{ab}	96.8^{cde}	85.8^{abcde}	3.2^{cd}	14.2^{ab}	2.8^{b}	6.2^{a}	25.2^{abc}	19.6^{bc}	74.8^{bcde}	80.4^{bcde}
150 ppm NAA	48.5^{cdefg}	42.3^{abc}	99.4^{a}	94.2^{a}	0.6^{gh}	5.8^{ef}	0.3^{cdefg}	2.5^{cdef}	28.2^{a}	25.3^{a}	71.8^{defg}	74.7^{f}
0 ppm NAA (Water spray)	64.6^{cd}	45.0^{a}	96.9^{cd}	89.5^{abcd}	3.1^{cdef}	10.5^{bcd}	2.0^{bccdef}	4.7^{bc}	26.2^{ab}	18.4^{bcd}	73.8^{def}	81.6^{bcd}
Control (Farmer's Practice)	62.0^{cde}	$26.5d^{e}$	98.9^{b}	93.5^{ab}	1.1g	6.5^{efg}	0.7	1.7^{fg}	24.3^{abcd}	21.3^{ab}	75.7^{bcd}	78.7^{cde}
Mean	68.5	37.1	97.3	88.7	2.7	11.3	2.0	4.1	23.5	18.6	76.5	81.4
SE m ±	6.22	3.02	0.56	1.70	0.56	1.70	0.54	0.63	1.44	1.63	1.44	1.63
CD (5%)	16.45	7.99	1.47	4.50	1.47	4.50	1.42	1.67	3.82	4.32	3.82	4.32

[Different alphabets show significant difference and same alphabets show non-significant difference among treatments] it was observed that foliar spray of 75 ppm NAA decreased flower drop to 96.5% and increased fruit set to 3.5% which significantly differed from the control where no spray was done. Water spray during both the stages in April-May also showed significant difference in increasing the fruit set (3.1%) and reducing the flower drop (96.9%) as compared to control. The data indicated that fruit setting in May flowering can be increased even through water spray but the fruit drop cannot be controlled through water foliar spray and hence fruit retention was lower in water spray.

The foliar sprays of 100 ppm NAA in August flowering decreased the flower drop to 81.5% and increased fruit set to 18.5% (Table 1). Application of 125 ppm NAA also decreased the flower drop to 85.8% and increased the fruit set to 14.2%. Significantly higher fruit set and lower flower drop were observed in both the treatments as compared to control and water spray. However, higher flower drop (94.2%) and lower fruit set (5.8%) were recorded in 150 ppm NAA and these values were statistically at par with control. No significant differences were observed in reduction of fruit drop and increase in fruit set with water spay and control treatments during August flowering.

The flowering and fruit behaviour of sapota tree was very peculiar. It was observed that number of flowers per shoot during May was more as compared to July-August but the fruit set per cent was reverse in both the flushes. This might be due to the less competition for fruit set, availability of space for each flower and distribution of assimilates to sink. Furthermore, it had been reported that with more assimilates plants remain physiological more active and maintain favourable C/N ratio in terminal shoots which subsequently promoted reproductive growth and hence more fruit set per cent was recorded[9].

The results are supported by Nagargoje *et al.*[10] who reported that application of 100 ppm NAA during 50% flower opening and pea stage in August-September in sapota cv. *Kalipatti* increased fruit setting from 38.72% (control) to 47.58%. Increased fruit set (%) with foliar application of 100 ppm NAA before flowering in sapota was also reported by Das & Mahapatra[5], Kadam *et al.*[11] and Aggarwal *et al.*[12] Contrarily, Ray *et al.*[13] reported higher fruit set with higher dose of NAA (300 ppm) after SADH (100 ppm) sprays in sapota cv. *Cricket Ball* under tropical conditions. But in Punjab conditions, increased dose of NAA have resulted in poor fruit setting in sapota. This might be due to higher average temperature during the summer season under sub-tropical conditions.

Effect of NAA on fruit drop and retention

The data presented in Table 1 clearly indicates the significant effect of NAA treatments on fruit drop and fruit retention of May flowering over the control. Significantly lower fruit drop (16.5%) was recorded in foliar application 100 ppm of NAA. However, the fruit drop was significantly higher (28.5%) in 150 ppm NAA application. It was observed that with the increase in NAA concentration, the fruit drop (%) was increased. Higher fruit drop (26.2%) was recorded in water spray treatment which was statistically at par with control (24.3%) and 125 ppm NAA (25.2%) and higher than all other treatments. Foliar application of 100 ppm NAA before flowering and pea stage increased fruit retention significantly (83.5%). Significantly lower fruit retentions were recorded in water spray (73.8%) and control treatments (75.7%). Furthermore, higher fruit drop and lower fruit retention were observed with the increase in the concentration of NAA (150 ppm).

The data with respect to effect of NAA on fruit drop and fruit retention in August flowering are given in Table 1. The results showed that foliar application of 100 ppm NAA at flowering and pea stage was found significantly superior over other treatments including control in reducing the flower drop and increasing fruit set. The results revealed that foliar application of 50 ppm NAA showed significant reduction (16.3%) in fruit drop as compared to control (21.3%). However, non-significant increase in fruit drop was noticed with 75 ppm NAA. The foliar sprays of 100 ppm NAA at both the stages significantly reduced the fruit drop to 11.3% and increase the fruit retention to 88.8%. Furthermore, the trend was reserved with the increase in the concentration of NAA (125 ppm, 150 ppm). However, water spray during both the stages in July-August did not show any significant difference in decreasing the fruit drop and increasing the fruit retention as compared to control.

The results indicated higher fruit set and fruit retention and lower fruit drop with the application of 100 ppm NAA at flowering and pea stage during May and August flowering in sapota. Non-linear dynamics in fruit drop (%) and fruit retention (%) were noticed with increase in NAA concentration from 50-75 ppm during July-August. This might be due to the unpredicted rains during rainy season after the foliar spray. Higher fruit setting had been observed during August flowering as compared to May flowering. This might be due to higher relative humidity and relatively lower temperature during these months as compared to April-May. Higher temperature coupled with less relative humidity resulted in desiccation of flower buds, and hence lower fruit setting was observed in May flowering.

Furthermore, it has been hypothesized that increased concentration of NAA (125 & 150 ppm) coupled with higher temperature under subtropical conditions has negative effect on fruit setting and fruit drop in sapota. Our results are supported by findings of Rathod & Amin[14] who stated that 5.3% higher fruit retention was recorded with foliar application of 100 ppm NAA in sapota cv. *Kalipatti*. Similarly, Kadam *et al.*[11] reported lowest fruit drop (58.34%) with foliar application of 100 ppm NAA during fruit set stage in sapota. Higher fruit retention was also reported by Nagargoje *et al*.[10] in sapota cv. *Criket Ball* with superimposed 100 ppm NAA application with 400 ppm cycocel. NAA application resulted in lower fruit drop and hence, higher fruit retention by inhibiting abscission layer.

Effect of NAA on fruit quality and yield parameters

The data pertaining to the effect of NAA on fruit quality and yield in sapota are given in Table 2. The data showed that fruit length and fruit breadth were also influenced by the application of NAA in sapota. Significantly higher fruit length (5.90 cm) was observed with 50 ppm NAA. It was statistically at par with 125 ppm NAA (5.8 cm) and water spray (5.8 cm) but higher than all other treatments. Similarly, significantly higher fruit breadth (5.70 cm) was recorded with water spray than all other treatments except 50 ppm (5.60 cm) and 100 ppm (5.60 cm) NAA foliar sprays. Maximum fruit weight (104 g) was recorded in 100 ppm NAA which was significantly higher than all other treatments including control. However, lowest fruit weight (82.50 g) was recorded in 150 ppm NAA which was statistically lower than that of control (92.90 g).

The data pertaining to physiological loss of weight (PLW) after ripening of fruits showed minimum PLW loss (7.56%) in treatment 100 ppm NAA which was statistically lower than all other treatments except 125 ppm NAA (9.04%). However, maximum PLW (12.12%) was observed in treatment 150 ppm NAA which was significantly higher than all other treatments except 50 ppm and 75 ppm NAA.

Non-significant variation in number of seed per fruit, seed length and seed breadth were observed among treatments. Seed weight per fruit varied significantly among treatments. Maximum seed weight (2.35 g) per fruit was recorded in 75 ppm NAA which was significantly higher than all the treatments except 125 ppm NAA (2.25 g). Minimum seed weight (1.95 g) per fruit was recorded in 50 ppm NAA which was statistically at par with treatment 100 ppm NAA. Maximum TSS (22.80 ^{o}Brix) was recorded in control which was statistically at par with 100 ppm NAA (22.50 ^{o}Brix) and significantly higher than all other treatments. However, minimum TSS (19.80 ^{o}Brix) was recorded in water spray treatment. Minimum acidity (0.20%) was recorded in 100 ppm NAA treatment which was significantly lower than all

Table 2 — Effect of NAA on fruit quality and yield of sapota cv. *Kalipatti* at Ludhiana during 2016 and 2017 (mean data of two years)

Treatment	Fruit length (cm)	Fruit breadth (cm)	Fruit wt. during harvesting (g)	Fruit wt. after ripening (g)	*PLW (%)	No. of seeds/ fruit	Wt. of seeds/ fruit (g)	Seed length (mm)	Seed breadth (mm)	TSS (^{o}Brix)	Acidity (%)	Yield (kg/tree)
50 ppm NAA	5.90^{a}	5.60^{ab}	98.60^{ab}	86.90^{bc}	11.87^{ab}	2.00	1.95^{cdefg}	2.31	1.25	22.10^{bc}	0.27^{ab}	65.20^{abc}
75 ppm NAA	5.50^{ef}	5.40^{bc}	96.00^{bcd}	85.07^{bcd}	11.39^{abc}	2.00	2.35^{a}	2.45	1.26	21.90^{cd}	0.24^{cd}	68.20^{ab}
100 ppm NAA	5.70^{cd}	5.60^{ab}	104.00^{a}	96.13^{a}	7.56^{fg}	2.00	2.02^{cdef}	2.39	1.34	22.50^{ab}	0.20^{e}	75.90^{a}
125 ppm NAA	5.80^{bc}	5.40^{bc}	88.67^{def}	81.40^{bcdef}	8.20^{def}	2.00	2.25^{abc}	2.35	1.22	21.60^{cde}	0.25^{c}	61.20^{bcd}
150 ppm NAA	5.60^{de}	5.30^{cf}	82.50^{efg}	72.50^{g}	12.12^{a}	2.00	2.32^{ab}	2.28	1.28	20.50^{ef}	0.28^{a}	42.60^{efg}
0 ppm NAA (Water spray)	5.80^{bc}	5.70^{a}	96.20^{abc}	87.10^{b}	9.46^{d}	2.00	2.16^{cd}	2.37	1.22	19.80^{fg}	0.28^{a}	48.20^{e}
Control (Farmer's Practice)	5.60^{de}	5.40^{bc}	92.90^{bcde}	84.50^{bcde}	9.04^{de}	2.00	2.06^{cde}	2.38	1.26	22.80^{a}	0.27^{ab}	46.20^{ef}
Mean	5.70	5.49	94.12	84.80	9.95	2.00	2.16	2.36	1.26	21.60	0.26	58.21
SE m ±	0.05	0.06	2.64	2.68	0.70	0.00	0.06	0.02	0.02	0.41	0.01	4.78
CD (5%)	0.14	0.15	6.97	7.08	1.84	NS	0.15	NS	NS	1.08	0.03	12.64

[Different alphabets show significant difference and same alphabets show non-significant difference among treatments, ***PLW**- Physiological loss in weight] other treatments. However, maximum acidity (0.28%) was recorded in 150 ppm NAA and water spray which was statistically at par with control. Significantly higher fruit yield (75.90 kg/tree) was recorded in 100 ppm NAA followed by 75 ppm NAA and 50 ppm NAA. However, significantly lower fruit yield (42.60 kg/tree) was recorded in 150 ppm NAA. The reduction in the fruit yield with higher dose of 150 ppm NAA was probably due to the lower fruit set and fruit weight.

The results showed higher fruit quality and yield with foliar application of 100 ppm NAA during July-August flowering. Fruit size in terms of fruit length and breadth was also significantly influenced by the application of water and lower doses of NAA. Water and lower doses of NAA probably could maintain the temperature of the fruits and hence prolonged the cell division period during summer months. Increase in fruit weight might be due to cell elongation of vacuoles and increased plasticity of the fruit. However, the higher doses alter the physiology of tree and hence affect the fruit size. The enhancement in fruit size might be due to increased cell division, elongation and expansion. Fruit weight increase might be due to cell elongation by enlargement of vacuoles and loosening of cell wall. The results are in close conformity with the findings of Agrawal & Dikshit[12] in sapota and Syamal *et al.*[15] in papaya.

The reason of higher fruit yield per tree is may be due to higher fruit setting and fruit retention with NAA sprays. Our results are supported by the findings of Rathod & Amin[14] who reported higher fruit weight with foliar application of 100 ppm NAA in sapota cv. *Kalipatti*. Similarly, higher fruit weight was reported by Aggarwal & Dishit[16] with foliar application of 100 to 200 ppm NAA in Cricket Ball. Higher level of TSS with 100 ppm NAA foliar application may be due to the accumulation of metabolites and conversion of starch into sugars during fruit maturity stages. Observations made by Rathod & Amin[14] strengthened our results which stated that all concentration of 75-100 ppm NAA observed to increase TSS in sapota fruits cv. *Kalipatti*. Significant increase in TSS (21.86%) with NAA foliar application may be due to enhanced conversion of complex sugars into soluble sugars in fruits[17,18].

Lower fruit acidity in sapota with 100 ppm NAA application was also reported Aggarwal & Dishit[16] which clearly indicated the significant effect of NAA on fruit acidity. This might be due to early maturity and utilization of acids during respiration after harvesting.

However, recently, Ingale *et al.*[19] reported higher fruit TSS, and lower titratable acidity of sapota fruits with foliar application of 100 ppm NAA. In our study, lower doses of NAA had positive significant effect on fruit quality while the higher doses of NAA had non-significant effect on fruit quality than control[20]. No linear relationship was observed within doses of NAA and fruit quality and yields parameters in this experiment. The lower dose NAA (100 ppm) gave better results under sub-tropical conditions due to fact that temperature remains comparatively higher than tropical region and the efficacy of growth regulators (NAA) is more at higher temperature. The higher dose of NAA (150 ppm) resulted in poor fruit setting and hence poor fruit yield per tree was recorded under Punjab conditions.

Conclusion

The present study revealed more profuse flowering during May as compared to July-August in sapota under Punjab conditions. However, significantly higher fruit setting was recorded in July-August flushes. The data indicated that fruit setting in May flowering can be increased even through water spray but the fruit drop cannot be controlled through water foliar spray and hence fruit retention was lower in water spray. The foliar sprays of 100 ppm NAA in August flowering decreased the flower drop to 81.5% and increased fruit set to 18.5%. But, no significant differences were observed in reduction of fruit drop and increase in fruit set with water spray and control treatments during August flowering. Foliar application of 100 ppm NAA during July-August flushes resulted in higher fruit quality and yield in sapota. Significantly lower PLW (7.56%) after ripening of fruits was recorded in treatment 100 ppm NAA. However, higher dose of NAA (150 ppm) resulted in poor fruit setting, more PLW and fruit yield. Fruit size in terms of fruit length and breadth was also significantly influenced by the application of water and lower doses of NAA. The study concluded that fruit setting, quality and yield can be enhanced significantly at farmer's field with foliar application of 100 ppm NAA at flowering and pea stage during July-August in sapota. cv. *Kalipatti* under subtropical conditions.

Conflicts of interest

Authors declare no conflict of interests.

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